R&D actinic blank inspection microscope

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EUV mask blank defect inspection

One of the most challenging requirements for the next generation EUV lithography at 13.5 nm or even 6.x nm is an extremely low amount of critically sized defects on masks and mask blanks for mass chip production. Fast and reliable inspection of mask blanks is still a challenge. Here we present the current status of the development of our actinic Schwarzschild objective based microscope [1] operating in dark field with EUV discharge produced plasma source.

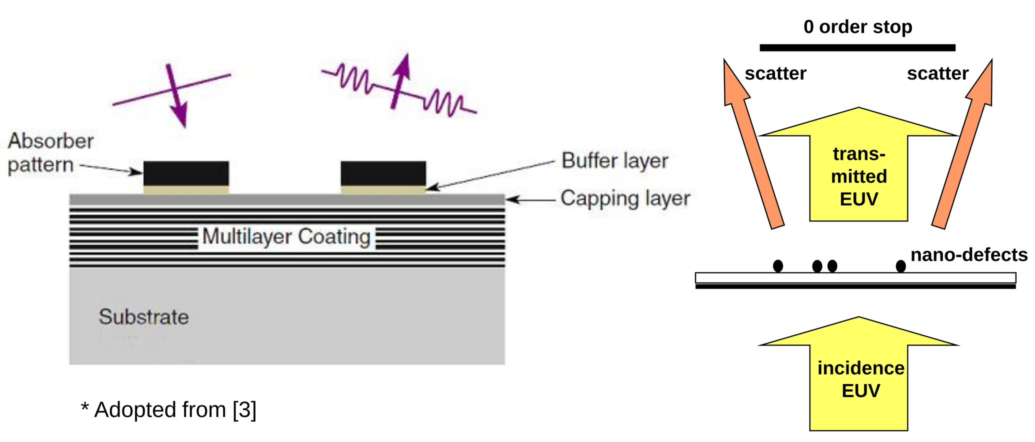
The mask blank and the corresponding reticle must have less than 0.003 printable defects/cm^2 of 25 nm [2], i.e. defects which could affect the quality of structures of the final wafer. This determines the maximal flux inhomogeneity which is allowed to be produced by defects on mask. Correspondent physical dimensions of critical defects on top of the mask blank substrate or inside the multilayer (ML) are still not exactly defined. Formulating critical defect size will determine the required quality level which must be applied to technological process related with mask production.

Most of current projects for mask blank inspection are settled on low-resolution dark-field imaging with large field of view (FOV) and direct EUV detection [3]. Such a system can achieve greater sensitivity and speed for static exposures with a laboratory source. Additionally the inspection has to be done actinically (at the exposure wavelength of the stepper in the lithography process), because the reflecting ML of the mask blank is designed for that wavelength. Inspection with other wavelengths can detect other inhomogeneities, which are not necessarily critical defects or printable under EUV exposure [4].

For microscope performance characterization natural defects and artificial pits and bumps created on top of multilayer mirror surfaces were investigated. Defect size sensitivity of actinic inspection in dark field mode without resolving the defects is under study. The dependency between defect shape, size and position in relation to the ML surface and its scattering signal are discussed.

Dark field microscopy for defect inspection

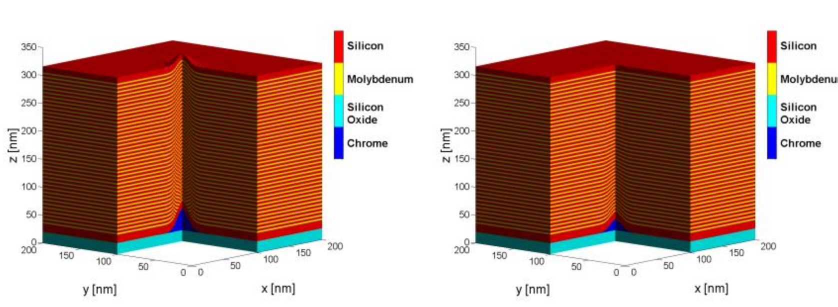
Amplitude and phase defects can be detected efficiently in actinic dark field mode

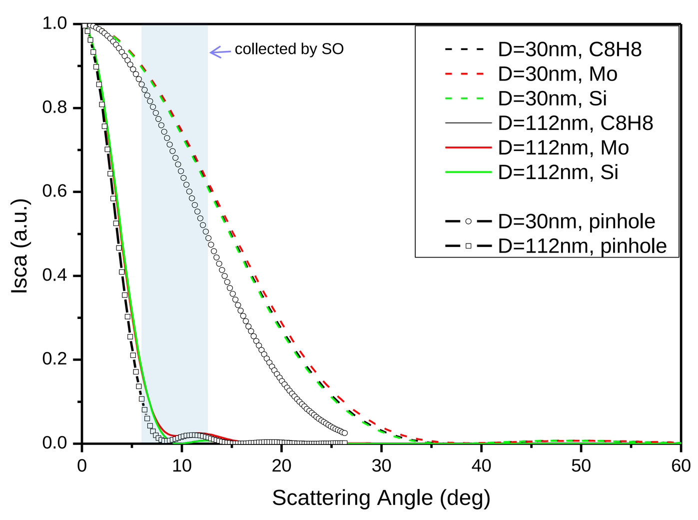


Sketch of patterned multilayer (left), scheme of dark field mode (right)

Comparison of Fraunhofer diffraction on pinhole vs. Mie scattering

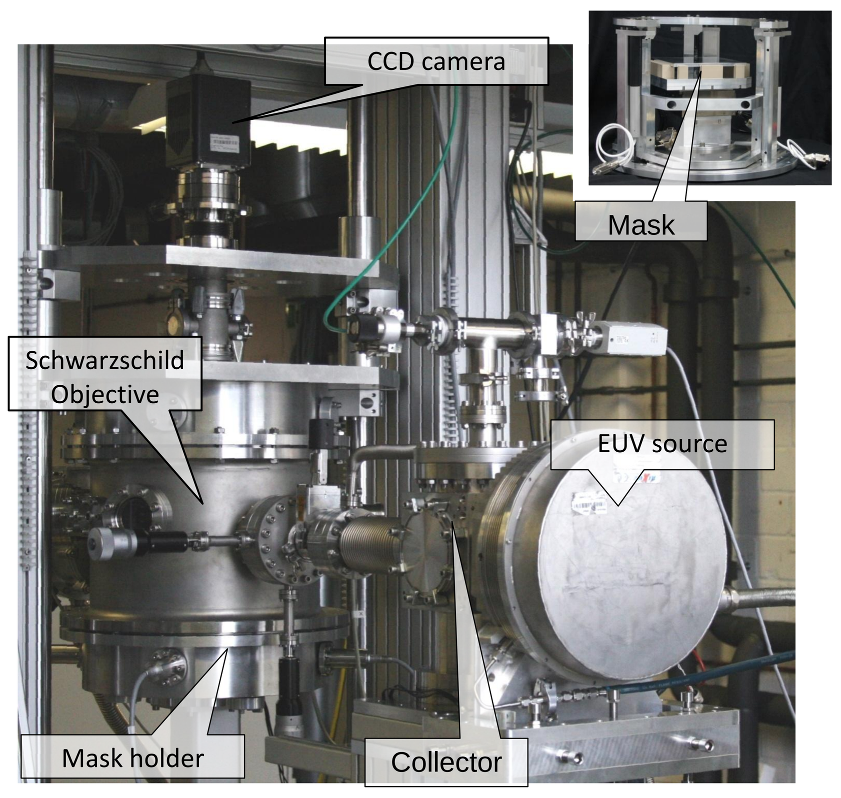
- Amplitude defects
- Phase defects





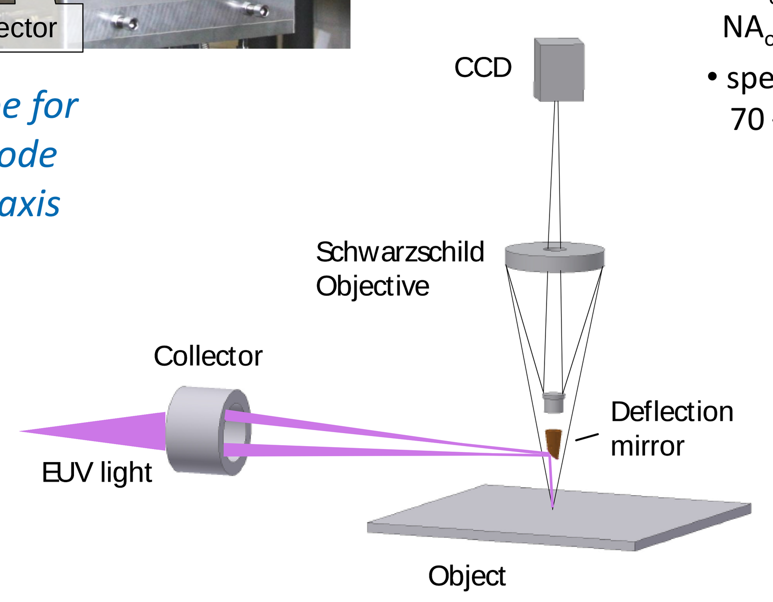
Defects in a multilayer mirror – with and without impact on its surface.

The experimental dark field reflection microscope based demonstrator for defect inspection has been successfully realized.



EUV dark-field microscope for operation in reflection mode and mask holder with 5-axis nanometer precision positioner (inset).

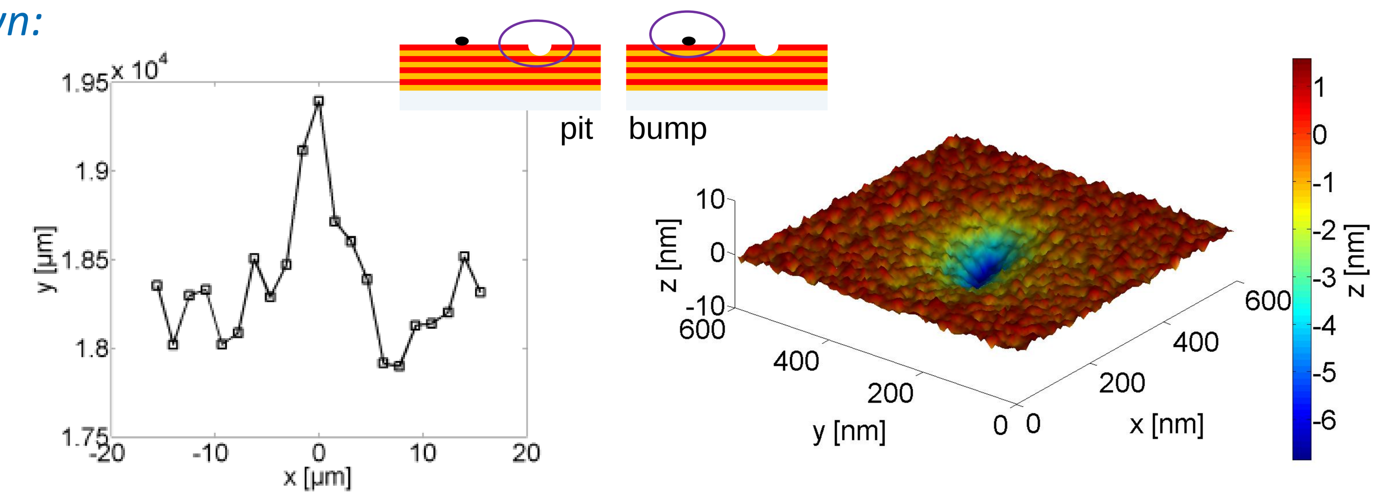
- central wavelength: 13.5 nm
- Xe-discharge source
  - ~ 0.5 mJ/sr/pulse/2%bw, 50 Hz
  - ~ diameter: 500 – 800 µm
- grazing incidence ellipsoid collector
  - $NA_{object,min}=0.03$, $NA_{object,max}=0.04$
  - $NA_{source,min}=0.14$, $NA_{source,max}=0.16$
- iris aperture, Zr filter, deflection ML mirror 45°
- central stop => dark field operation
- mask blank holder and positioning (± 25 mm)
- FOV=650 µm, RES~600 nm limited by CCD (1024^2 pixel of size 13 µm, 1.1 fps, 10 e$^-$/ph)
- Schwarzschild objective
  - 21x, focal length 27 mm
  - $NA_{object,min}=0.11$, $NA_{object,max}=0.21$
  - specified resolution 70 – 100 nm



Scheme of the setup

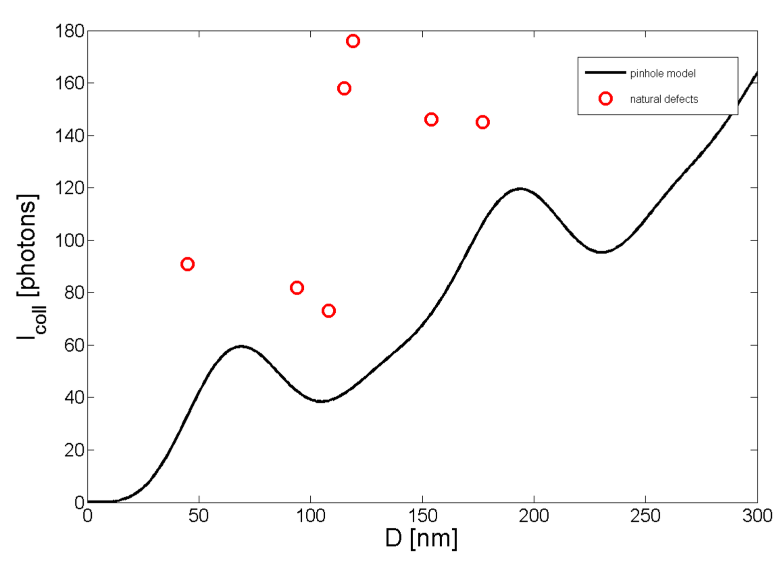
Experimental results and detection limitations

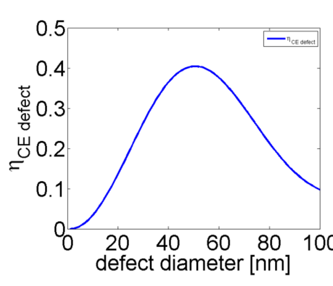
Programmed structures (bumps and pits) and natural defects both on multilayer mirrors have been investigated and characterized by AFM, the smallest defect is shown:



Profile of a dark field EUV image of ML mirror sample (left) and the corresponding AFM scan (right). The equivalent sphere diameter is 45 nm, the height is 7 nm.

Number of photons collected by CCD from a single defect - simulated by pinhole model for irradiation dose of 1.6 mJ/cm^2 (all losses in the system are considered) in comparison with investigated natural defects (left), collection efficiency of scattered light from a defect as a function of its size (right).

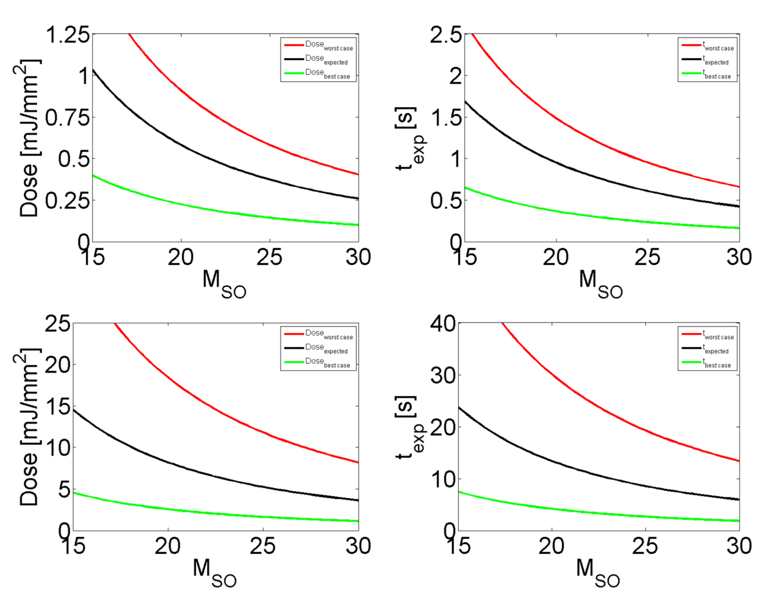




Simulation model based on diffraction distribution of a pinhole has been developed to calculate the amount of detectable photons as a function of defect diameter. The model has been cross checked by the experimental results from natural defect inspection.

Limitations caused by detector, optics, sample movement and source performance. Goal is to have SNR = 6 and detect 30 nm defects, for extendibility also 20 nm sensitivity is shown

$$SNR = \frac{S_{defect}}{\sqrt{S_{roughness}}} \qquad Dose \sim \frac{1}{A_{defect}{}^2 \eta_{CE}{}^2} \qquad t_{exp} \sim \frac{Dose}{P_{source} \cdot A_{source}}$$



Parameter	Worst case	Expected case	Best case
QE_{CCD}	0.40	0.40	0.60
$\eta_{scatt-flare}$	0.02	0.015	0.01
$\eta_{scatt-defect}$	0.40	0.40	0.40
$\eta_{collect-flare}$	0.15	0.20	0.25
$\eta_{collect-defect}$	0.20	0.25	0.30
R_{SO}	0.36	0.36	0.36
d_{pixel} [µm]	13	13	13
$R_{deflection}$	0.45	0.45	0.45
T_{filter}	0.30	0.30	0.30
T_{gas}	0.70	0.70	0.70
$R_{collector}$	0.45	0.45	0.45
$\varphi_{obj-coll}$ [°]	5	5	5
M_{coll}	6	6	6
d_{source} [µm]	400	400	400
P_{source} [W/2π/2 %b.w.]	1	1	1

Required dose in the object plane to achieve SNR = 6 for 30 nm defects (1st row, left), corresponding exposure time (1st row, right); Required dose and corresponding exposure time for 20 nm defects and the same SNR (2nd row) and table of used parameter.

Conclusion

- Proof of principle shown with current demonstrator, limitations have been analyzed – M_{SO} = 21 is suitable.
- Programmed structures (pits and bumps) and natural defects on multilayer mirrors have been measured. Defect detection limits with a large field of view and moderate magnification were investigated in terms of required source photon flux and detection camera performance.
- We are confident that an economic solution for sub-30 nm sensitivity and acceptable throughput can be achieved.

[1] A. Maryasov, S. Herbert, L. Juschkin, R. Lebert, K. Bergmann, Proc. SPIE 7985, 79850C (2011)

[2] O. Wood, EUV Lithography: Approaching Pilot Production, International Workshop on EUV Lithography, June 21-25, 2010, Maui, Hawaii

[3] K. Goldberg, I. Mochi, J Vac. Sci Technol. B 28, C6E1-C6E10 (2010)

[4] http://www.imec.be